Moving Towards Unmanned Systems
Live Virtual & Constructive Interoperability

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Abstract

Innovative technological advances have enhanced the capability of Unmanned Systems contributing to warfighting capabilities in support of both operational and tactical objectives. The full capability of Unmanned Systems, is obtained only if uninterrupted transfer of vehicle control, and sensor data dissemination can occur rapidly across command and control echelons. Interoperable Unmanned Systems are powerful assets in a network centric environment.

NATO has been at the forefront of identifying the need for standardization and the promotion of interoperability for Unmanned Systems and has defined the STANAG 4586 protocol. This protocol identifies the standard interfaces required for shared asset control and data dissemination by defining five levels of interoperability.

The Naval Air Systems Command's (NAVAIR) Integrated Battlespace Simulation and Test (IBST) Department conducts ground-based testing of avionics systems, weapons systems, and platforms. Within its facilities, simulators and stimulators are used to provide immersive realistic environments to Systems Under Test (SUT). These systems are placed in one of IBST's anechoic chambers and tested using a combination of simulation and stimulation, to provide radio frequency, electro-optical, and laser stimuli replicating real signals. Modeling and Simulation (M&S) is a necessary component to bring these stimulators together in a coherent environment.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JAN 2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE **Moving Towards Unmanned Systems Live Virtual & Constructive Interoperability**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **NAVAIR,Integrated Battlespace Simulation and Test (IBST) Dept,48150 Shaw Road Unit 5 Building 2109,Patuxent River,MD,20670-1907**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Live-Virtual Constructive Conference, 12-15 Jan 2009, El Paso, TX

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**12**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Using the STANAG 4586 interoperability standard, IBST's Air Combat Environment Test and Evaluation Facility (ACETEF) has integrated a generic Ground Control Station (GCS) capability that supports Live, Virtual, and Constructive (LVC) testing for Unmanned Systems. ACETEF has added the integrated Unmanned Systems Control Station capability within the facility and has the ability to interface with live assets in the chambers as well as other IBST T&E resources. This environment supports testing of hardware, software and mission planning tools of various Unmanned Systems and provides the opportunity to test various STANAG compliant Unmanned Systems through use of LVC test techniques.

In September 2007, ACETEF determined that both Open Unmanned Mission Interface (UMI) and Vehicle Control Station (VCS) 4586 would be suitable tools for support of live and virtual tests, and that the Multiple Unified Simulation Environment (MUSE) would be suited for constructive tests. Integrating these tools with the Vehicle Specific Modules (VSM) enabled two successful proof of concept tests; the Kestrel in March 2008 and Silver Fox three months later, in June. Using Open UMI and VCS 4586, ACETEF successfully controlled the Unmanned Systems' communications using the STANAG protocol.

ACETEF's early involvement using the STANAG 4586 standard has enabled the facility to capitalize on industry resources and make significant and rapid progress for the U.S. Navy and the Department of Defense to provide test resources for Unmanned Systems control. ACETEF supports the research and testing of future STANAG 4586 compliant systems and with an established history of comprehensive and successful installed system testing will continue to play a significant role in the development of integrated systems-of-systems test capability, resulting in unparalleled interoperability.

IBST

The Integrated Battlespace Simulation and Test (IBST) Department is NAVAIR's point-of-entry for modeling and simulation of the battlespace environment and NAVAIR's lead for the development and creation of synthetic and virtual battlespace environments in support of research, development, testing, training, systems evaluation and experimentation. For large-scale simulations used across an acquisition lifecycle, the department is also the lead for model management, scenario development, interface support, distributed simulation expertise, and Verification, Validation, and Accreditation (VV&A). The IBST Department manages NAVAIR's Research, Development, Test and Evaluation (RDT&E) Domain and, as part of the NAVAIR CIO process, oversees the RDT&E Governance Board.

The IBST Department operates, maintains and manages a number of Navy installed system test facilities to support test and evaluation events for a variety of aircraft avionics and weapon systems. These facilities provide both physical and simulated environments and are designed to place test articles in a realistic, yet simulated combat environment. From launch to recovery, every phase and aspect of a mission is simulated to enable engineers to capture data necessary to assess the efficiency and capabilities of the avionics or weapons systems under test. Real-world threat signals are produced to evaluate avionics and sensor system performance while studying and identifying the Electromagnetic Environmental Effects (E3) these and other signals have on the avionics and other collocated systems. Pattern unit cockpit training systems are manufactured and placed into simulated combat environments to assess the efficiency of cockpit layout and to evaluate aircrew workload and effectiveness; while a multitude of communications simulations provide assessment of aircraft and aircrew communications and interoperability capabilities. Additional testing provides ground radar cross-section measurements, missile fuse characterization measurements, and overall assessment of the entire kill-chain, from target identification to target engagement, including damage assessment and indication.

IBST operates and maintains the following:

- Air Combat Environment Test and Evaluation Facility (ACETEF)
- Integrated Battlespace Arena (IBAR)
- Surface/Aviation Interoperability Lab (SAIL) Branch
- Electromagnetic Environmental Effects (E3) Facilities (TEMPEST/EMC/ NERF/EMP)
- Missile Engagement Simulation Arena (MESA)
- Radar Reflectivity Lab (RRL)
- Joint Integrated Mission Model (JIMM) Model Management Office (JMMO)
- Next Generation Threat System (NGTS) Model Management Office (NMMO)
- NAVAIR RDT&E Base Area Networks

Background

IBST's Air Combat Environment Test and Evaluation Facility (ACETEF), as an Installed System Test Facility (ISTF), is working with UAV simulation and testing on various projects supporting the Office of Naval Research (ONR) Intelligent Autonomy (IA) program in FY 2005 - FY2007. The goal of the IA project was to develop and demonstrate autonomous control and human interface technologies for the simultaneous management of 5-10 heterogeneous unmanned systems. In order to accomplish this, mission planning systems were developed and integrated, significantly reducing the need for human intervention.

During the month of October 2007, ACETEF supported Fleet Synthetic Training (FST) with the Multiple Unified Simulation Environment (MUSE) UAS mission planner, the MetaVR payload visualization tool, and the Joint Semi-Automated Forces simulation environment generator (JSAF). The project team provided technical software support as well as human factors support of Concept of Operations (CONOPS) development, from the point of UAS target identification through orders to release weapons on an identified simulated target.

In FY 2007, ACETEF developed a special simulation environment that interfaces to the Unmanned System Research and Development Lab (USRDL) USS vehicle simulation, Global Visual Program (GVP) viewer, and Georgia Tech Research Institute (GTRI) UAS Automatic Identification System (AIS).

Project

This paper is based on the work performed by the team, under the ACETEF Upgrade Project.

The objective of the ACETEF Upgrade was to build a UAS Test Capability, integrated with an environment generator and appropriate hardware, to support Live Virtual and Constructive (LVC) testing of a variety of Unmanned Air Vehicle (UAV) platforms, both in chamber and air. This capability provides a secure, simulated, repeatable, integrated environment to test and evaluate UAVs and to evaluate the CONOPS of various UAV systems.

Selection of Software Suites

ACETEF's research indicated that, to develop and integrate a UAS test capability that is not platform specific and that supports live, virtual and constructive testing within reasonable cost constraints, it was best to use a suite of software packages to simulate the ground control.

Trade Study for Software Selection

While the objective was to design the capability to be as generic as possible, the team understood that given the current stove pipe development of UAVs and infancy of integration standards, there would be limits on the generic capability of the simulated Ground Control Station. This is due to:

- System specific communication data language
- Interfacing with Vehicle Specific Modules (VSMs) – more involved for bigger systems
- Other system specific unique requirements of systems
- Lack of established interfacing standards
- Evolving standards

While recognizing the limitations placed on a true plug and play type Ground Control Station, due to VSMs for an Unmanned Aircraft System (UAS), the capability was designed to have as much of an open architecture as possible.

The development of interoperable UAV systems, while still in its infancy, has begun maturing - developing from a chalkboard idea to standard message formats

(STANAG 4586), common data links (STANAG 7085), and a plethora of other open format standards.

STANAG 4586 has emerged in the forefront in defining interface standards to move towards plug and play systems for UAVs. Put forth by NATO, it is gaining acceptance within the UAS community. The STANAG 4586 concept is designed around an architectural structure where functional components within the system are isolated from each other through interfaces, and within the interfaces. This standard enables developers to create and verify air vehicle components independently of payload and data link components, thus allowing new modules to be added to a UAV Control System (UCS) without affecting the integrity of the entire Core UAV Control Station (CUCS). The STANAG 4586 Data Link Interface was defined to provide separation between air vehicle, payload, and data link functionality, with the payload functionality further supporting additional modularity through the subdivision of payloads into specific payload types.

In order to narrow down the selection of Unmanned Air Vehicle (UAV) control station simulation software, ACETEF did a trade study based on the following criteria:

- Generic / Interoperability
- Support of Current and Evolving Standards
- ACETEF Integration
- Operator Operation/Simple Operator Controls
- Maturity and Acceptance for Current and Future Warfighter Support
- Live and Constructive Support
- Schedule and Cost

Different software packages bring in a variety of test capabilities that, when integrated, provide an improved generic Ground Station. Research also indicated that the best approach was to divide the software suites into two categories with respect to testing.

Control Station Software Packages

ACETEF's research identified three software packages to provide integrated LVC testing. Given the acceptance of STANAG 4586 in the UAS community, STANAG 4586 compliance was a key criterion for selection of the software for live and virtual tests

Live and Virtual – ACETEF identified two software packages:

1. VCS-4586: Developed by CDL Systems - a forerunner in the field of interoperability in unmanned systems since 1994. VCS-4586 is inexpensive, configurable, user-friendly software that has been operationally proven on more than eight different Unmanned Air and Sea Vehicles. It is the first Ground Control Station developed according to STANAG 4586 protocol for UAS interoperability. VCS–4586 incorporates full resolution digital video with real time metadata and MPEG processing (STANAG 4609). Still imagery is captured using STANAG 4545 (NITF 2.1) format. As an active participant in the STANAG community, CDL Systems is well positioned to incorporate any changes in the evolving standard. This philosophy feeds many other aspects of VCS. It has developed APIs allowing access most data resident in the VCS, including telemetry data and imagery.

2. Open UMI: Developed by NAVAIR contractor Defense Technology Industry, (DTI) Systems, is "user-friendly" and easily configurable. Open UMI is used in Navy circles. This software package is used extensively by USRDL to support Fire Scout and to do live testing of UAVs and UUVs. It utilizes STANAG 4586 for the Communication Data Language and is capable of controlling multiple vehicles as well as different types of vehicles. It has a simple user interface. While Open UMI has implemented a limited number of STANAG 4586 messages, its ease of use and local support via DTI systems, and availability of compliable code make it a great candidate for integration to support current and future testing of UAS. Having worked with the software before, it integrated easily and served as stepping stone to integrate the more complex VCS-4586. Further, it put ACETEF in a position to steer Open UMI's future development to suit Navy requirements.

For Constructive Testing:

3. The Multiple Unified Simulation Environment (MUSE) was chosen as it is widely accepted in the community and because of ACETEF's working knowledge of it, from previous projects. The MUSE provides support for simulated environments only and provides the user with a variety of aircraft (manned and unmanned) with preset flight characteristics and respective payload capabilities. While it does not have any man-in-the-loop capability, it is excellent for scenario testing and development.

The MUSE provides the largest number of fielded simulation systems for command and staff level training for UAVs. It supports control of multiple Intelligence, Surveillance, and Reconnaissance (ISR) and UAV types; multiple uplink/downlink communication protocols; a defined TCP/UDP interface to custom-developed user interfaces, multiple sensor types (including EO, IR, SAR, and MTI control), and a mission planner capable of providing a full-range of ISR and UAV mission planning capabilities.

Support Software Packages and Interfaces

The control station is a system-of-systems, thus there are many system-level software packages and interfaces that must be bridged to enable communication between the STANAG-4586 control stations and other systems. Several interface applications were written to facilitate the migration of data from one system to the next.

1. **JIMM:** JIMM is ACETEF's environment generator and acts as the backbone of our integration**.** JIMM is a powerful language based tool, event stepped environment generator with extensive built-in interface features. It is used to integrate various simulations together. The JIMM Environment Generator provides significant capability without additional investment. It allows multi-model integrations (from code to real systems). JIMM entities communicate with each other (and with outside entities) and provide powerful analytical output. JIMM is a mission level simulation model. It is also used to build the representative scenarios that provide a backdrop for the war gaming environment.

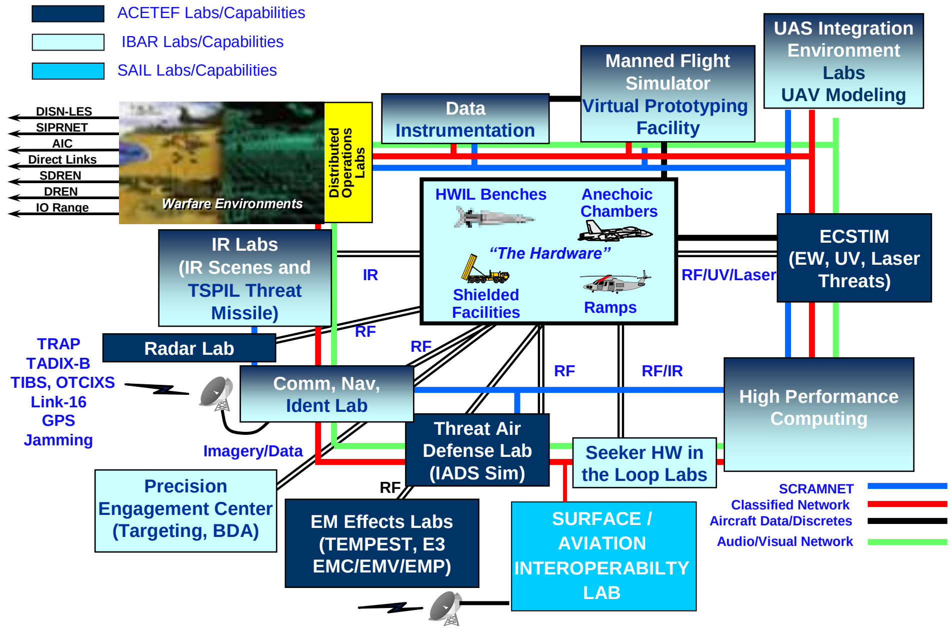
2. **VSM Monitor Interface:** The VSM Monitor application discovers and receives data from STANAG 4586 VSMs. This is achieved by using the VSM-CUCS interface defined by STANAG-4586. While OpenUMI or VCS-4586 takes control of the vehicle (LOI 4 or 5), the VSM Monitor acts as a secondary CUCS that only monitors data (LOI 2 or 3). The VSM Monitor sets up periodic output of important data, such as inertial and operating states. This data is then fed into the JIMM scenario or onto the LAN for distributed operations using DIS, TENA, etc. This allows simulated entities to perceive and react to the unmanned systems under test. The VSM Monitor also allows the operator to monitor STANAG-4586 messages, vehicle parameters, and sub-system alerts.
3. **Flight Gear Interface:** The Flight Gear interface allows data sent to the open-source Flight Gear visualization tool to be captured and injected into a JIMM scenario. This allows us to use systems such as Cloud Cap's Piccolo autopilot simulator to drive simulated UAVs within a synthetic environment. The data can also be forwarded to Flight Gear so that the visualization of data is uninterrupted.
4. **Aero Model:** The Aero Model is a parametric flight simulator used for medium-fidelity simulation of aircraft. Data sets were specifically developed for the simulation of small UAVs, such as an RQ-7 Shadow. A rotary version of the model was also developed for the purpose of simulating rotary UAVs, such as MQ-8 Fire Scout. The Aero Model allows ACETEF to provide simulated unmanned systems, whether through the JIMM environment or from the VSM side of the VSM-CUCS interface for STANAG-4586 capable systems.

ACETEF Lab Integration

The success of the ACETEF Upgrade project is not just defined by obtaining and integrating a STANAG compliant station, but also by being able to integrate it with the infrastructure, enabling ACETEF to leverage off the diverse testing capability available in house.

ACETEF integrates the various labs together via the shared memory structure of its environment generator JIMM. JIMM provides the warfare scenario and forms the core of the simulation with its shared memory structure. All subsystems shall interface with JIMM and be able to provide inputs to, and get data from, it's shared memory.

Integrated Battlespace Simulation and Test Architecture



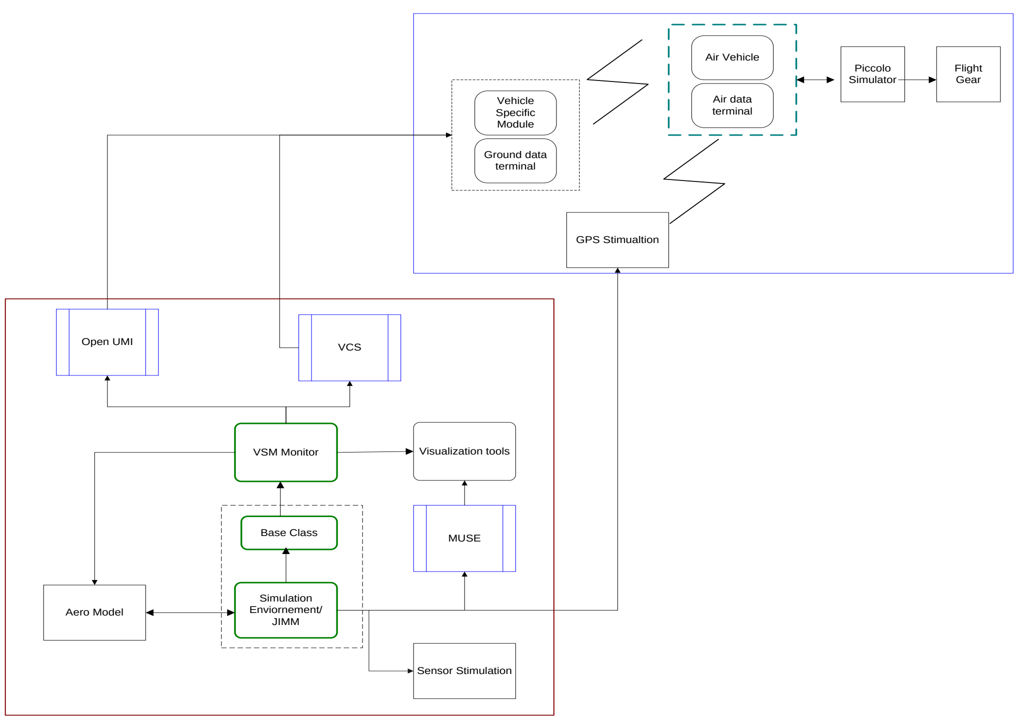


Figure 1: UAS Integration Lab & chamber connectivity diagram

Figure 2: UAS Integration Lab

1. Kestrel Demonstration: Conducted in April 2008 (Figure 3)

In April of 2008, a proof-of-concept test was carried out using the newly created generic UAS Control Station. The test subject was a Kestrel-T UAV from Defense Technologies, Inc, which was placed in the Aircraft Anechoic Test Facility (AATF) at IBST. The vehicle contained a Cloud Cap Piccolo autopilot, which communicated to the ground station via a Microhard radio. The Piccolo Ground Station was connected via RS-232 to a laptop running a Piccolo-compatible VSM. The aircraft itself was connected via a USB-CAN bus adapter to a laptop running the Piccolo Simulator which fed the Piccolo position and inertial updates as though it were actual flying. Additionally, the VSM Monitor application was used to feed aircraft data to other systems at ACETEF that would normally drive simulations and stimulators during aircraft testing.

During the first test, OpenUMI was used to feed a series of waypoints and loiters to the UAV. All test points were achieved in short order with little complication. The same test was performed using VCS-4586 and operating the aircraft in points navigation mode, which guides the aircraft to a specified point at a given altitude and speed. Except for some configuration issues that were corrected with assistance from the manufacturer, the test points were again met with little difficulty.

Figure 3: Kestrel demonstration in the Aircraft Anechoic Test Facility (AATF)

2. Silver Fox Demonstration: Conducted in June 2008 (Figure 4)

In June of 2008, a second test was performed to verify the UAS Control Station capabilities. This time, the system under test was a Silver Fox UAV, manufactured by ACR, Inc. that is presently in theater overseas. The Silver Fox was again built around the Piccolo autopilot, and tested in a similar hardware-in-the-loop configuration as the Kestrel-T. However, the Silver Fox came with an integrated Ground Control Station (iGCS) that took the place of the Piccolo Ground Station. Since the iGCS has the RS-232 hard wired into its systems, the only external interface that can be used is the Piccolo Ground Station's TCP/IP-based software interface. Both Piccolo-compatible VSMs supported this interface, so it was not an issue. The other significant difference in this test was that the Silver Fox UAV contained an EO/IR payload.

Both OpenUMI and VCS-4586 controlled the aircraft, and the team viewed the payload video on monitors. The team was not able to complete a payload-specific VSM in time for this testing, so they were unable to control the EO/IR from either system. If the UAV were STANAG-4586 compliant and the VSM had been provided by the vendor, this would not have been an issue.

Figure 4: Silver Fox demonstration in the AATF

Lessons Learned

Testing seldom goes as planned, but each difficulty is an opportunity to gain insight. Here are a few lessons learned during the unmanned systems test:

1. UAVs are non-traditional aircraft. Although inexpensive, generally developed with COTS, they tend to be built by companies who are not traditional aircraft producers. This is very advantageous for the users, but from the tester's perspective it means there are no standardized data protocols like the MIL-STD-1553 bus. It leads to stove piped development and creates problems for the tester. Custom cabling, custom software, and proprietary hardware and software can become major hurdles.
2. Though STANAG-4586 is gaining ground toward acceptance, it has not yet reached the critical mass required to make it ubiquitous within the unmanned systems community. For both demonstrations we used software developer's Piccolo-capable VSM. Neither vendor had payload VSM, limiting the range of the tests conducted. The payload control could not be tested due to unavailability of the payload VSM. The UAV community has to make an effort to establish standards in payload VSM, and vendors need to make it available to the customer as a package. It shall not fall on the tester's plate to develop one.
3. Version incompatibly raises serious issues. VCS 4586 is not backward compatible and Open UMI does not support newer versions of Piccolo autopilot. This resulted in switching versions for the asset to be capable of testing both software packages. Historically, the armed forces have used their assets for extended periods. If vendors

do not support backward compatibility, nor develop software for hardware currently available in the market place, it could create logistics issues.

ACETEF Upgrade Project Achievements

IBST has installed, interfaced and tested STANAG 4586 compliant Ground Control Stations for Live and Virtual tests with vehicle-in-the-loop. With VCS 4586, IBST has the capability of controlling a technically complex system. Open UMI might be in STANAG messages but has great potential due to its simplicity of use. This capability enables IBST to:

- Test STANAG compliant for various compliant UAS
- Test STANAG compliance of UAS as both STANAG and UAS develop
- Test Levels of interoperability
- Leverage off the knowledge to integrate upcoming standards

The Multiple Unified Simulation Environment (MUSE) has been installed, interfaced and tested, enabling IBST to support most simulation applications and support CONOPS development with:

- Scenario testing and development
- MUSE integrated aircraft (manned and unmanned) with preset flight characteristics
- Easy changes between AV configurations and payloads

The Control Station capability has been integrated with other IBST labs via the environment generator, the Joint Integrated Mission Model (JIMM). The lab connects through the RDT&E network to establish connectivity with IBST's anechoic chambers and SAIL. This provides IBST with the capability to:

- Introduce live and constructive assets in a LVC scenario along with the asset under test
- Develop, test and analyze scenarios and support CONOPS
- Perform varying levels of interoperability tests with SAIL and live assets
- Integrate with other labs and utilize the existing T&E assets moving from manned towards unmanned